Strong Injection Locking에 의한 반도체 레이저 다이오드의 직접변조대역 향상

Direct Modulation Bandwidth Enhancement of a Semiconductor Laser Diode by Strong Injection Locking

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Abstract

Characteristics of strongly injection-locked semiconductor lasers are analyzed. It is shown that strong injection locking can significantly enhance the laser diode modulation bandwidth.

There are renewed research efforts for injection-locked laser diodes (LDs) as they can provide enhanced performance for various applications [1-4]. The single mode rate equations for injection locked lasers [5-6] are employed as follows.

$$\frac{dS}{dt} = (G-\gamma)S + \frac{1}{L}\upsilon_g S\sqrt{\frac{S_i}{S}}\cos\theta + R \qquad (1)$$

$$\frac{d\Phi}{dt} = (\omega_j - \omega_o) + \frac{1}{2L}\upsilon_g\sqrt{\frac{S_i}{S}}\sin\theta \qquad (2)$$

$$\frac{dN}{dt} = -\frac{N}{\tau_e} - GS + \frac{I}{q} \qquad (3)$$

Here, where time-varying phase difference between master laser (ML) and slave laser (SL) is taken into account. S_i is the photon number injected into SL from ML through the optical isolator between them, and S is the photon number in the cavity of SL. By the small-signal analysis of these equations, the third order system function for injection-locked frequency response can be obtained. For free running LDs, the frequency response system function is of the second order.

We first found the maximum allowed phase detuning range between ML and SL. In order for the system to be stable, its poles should be located in the left plane in s-domain. Figure 1 shows the allowed phase detuning range for varying injection levels. The allowed maximum phase detuning value becomes larger as the injected photon number gets increased.

Figure 2 shows the direct modulation response for several injection levels at the allowed maximum phase detuning values shown in Fig 1. It shows clearly that a stronger injection locking can provide larger direct modulation bandwidth. For example, the modulation bandwidth of an injection-locked laser at (S_i/S) = -5 dB is about three times larger than that of a free-running laser.

Figure 3 shows modulation response for several phase detuning values with injection level fixed at –5 dB. Larger modulation bandwidth can be achieved by detuning the ML's phase. This point becomes clearer in Figure 4. The resonance frequency of the injection-locked laser is plotted for several injection-levels within each allowed frequency detuning range. The frequency detuning, $\Delta f = f_{SL} - f_{ML}$, can be determined from the following equation.

$$\Delta f = (v_g / 4\pi L)\sqrt{(S_i / S)}\sqrt{1+\alpha^2}\cos\left[\theta + \tan^{-1}(1/\alpha)\right]$$

Here, α is the linewidth enhancement factor.

The modulation response is a strong function of applied injection level and phase/frequency detuning values. Details of our analysis and its implications will be presented at the conference.

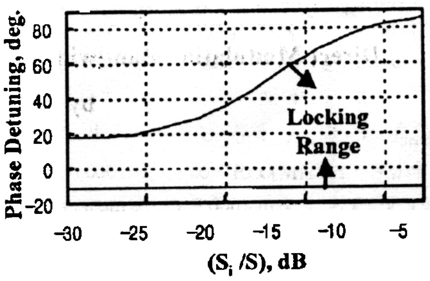

Fig. 1 Allowed phase detuning vs. (S_i/S) with stability considerations

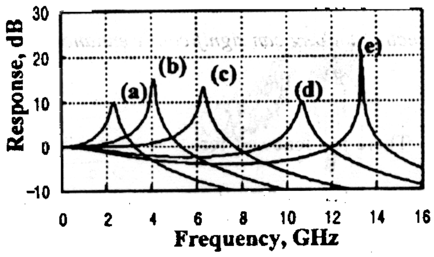

Fig.2 Modulation response for several injection levels with allowed phase detuning values, such as (a) free running laser, (b) (S_i/S) = -15dB (θ = 48 deg.), (c) (S_i/S) = -10dB (θ = 71 deg.), (d) (S_i/S) = -5dB (θ = 83 deg.), and (e) (S_i/S) = -3dB (θ = 85 deg.)

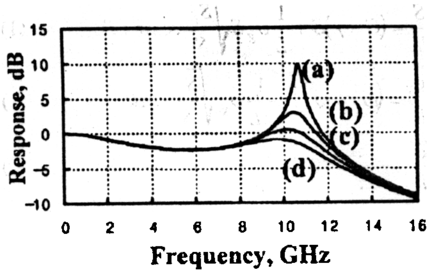

Fig. 3 Modulation response at a fixed injection level of -5dB over phase detuning values, such as (a) 83 deg., (b) 80 deg., (c) 70 deg., and (d) 60 deg.

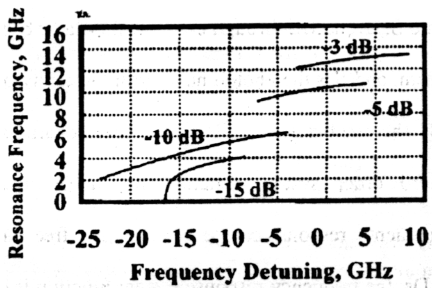

Fig. 4 Resonance frequency vs. frequency detuning over injection levels of -15 dB, -10 dB, -5 dB and -3dB

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